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The Virtual Ship – A New Capability in Support of Maritime Forces

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Aeronautical and Maritime Research Laboratory

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ABSTRACT

This report describes a concept for the Virtual Ship and highlights its potential application throughout all phases of the platform lifecycle. The technical requirements for implementing the Virtual Ship concept are described.

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Executive Summary

A key challenge in modern surface warfare is the integration of many different systems. These include on-board and off-board sensors, data fusion systems, command decision aids, command and control (C^2) systems, weapons and the platform itself. There is currently a gap in the capability to rigorously study these integration requirements in a laboratory environment. Additionally, the capability is lacking to comprehensively investigate the operational efficacy of new systems prior to their introduction to service.

The Virtual Ship will provide a facility through which these issues may be addressed. It will exploit modern computing capability, particularly distributed simulation technology, to bring together simulations of ship systems in order that warship operations may be simulated. The Virtual Ship will provide a human-in-the-loop capability in that human operators may interact in real time with the simulations just as they would interact with the real system.

The Virtual Ship will find application in support of a number of DSTO and ADF objectives. It will provide an environment within which the operational utility of sensors, signal processing techniques, data fusion techniques, command decision aids and weapon systems may be demonstrated and refined. It will enable the operational perspective to be accounted for in the laboratory, prior to expensive sea trials. It also provides a means by which system user requirements may be elicited in a controlled and cost effective manner.

These potential applications of the Virtual Ship are not limited to supporting the force in being. The significant advantage that a "virtual" environment offers is that of integrating models of systems that represent the latest technology, or represent future technological prospects. With these models the Virtual Ship may be used to assess the operational utility of concept platforms, or platforms proposed during an acquisition. The requirement for a new platform may be specified in terms of the Virtual Ship. The integration requirements associated with new systems may also be explored in the virtual environment. It is in this way that the Virtual Ship will support the capability development and acquisition processes.

The Virtual Ship will support the force in being through its contribution to training, tactical development, mission rehearsal and studies of operational concepts. In addition, exploiting the Virtual Ship from the earliest phases of the platform life will mean that these activities can be performed prior to the platform being manufactured. This offers the possibility that the Virtual Ship will facilitate a new platform being

introduced into service accompanied by mature training and operational doctrine that exploits the platform's unique capabilities.

The Virtual Ship will share a close relationship with operations research. Operations research has traditionally been concerned with mathematical modelling and constructive simulation. Measures of effectiveness are rigorously computed, often exploiting statistical techniques. The Virtual Ship will complement this capability through the fidelity it provides and through its ability to capture human performance characteristics. The concept that unifies them is that of supporting military decision-making.

The Virtual Ship will be based upon the High Level Architecture (HLA), which is a framework supporting distributed simulation. It enables individual simulation systems to exchange data over a network in such a manner that they may operate within a common virtual environment. The HLA will be customised to support the integration of simulation models in the maritime domain. The Virtual Ship Architecture (VSA) refers to those components required to simulate warship operations, over and above the components of the HLA.

The provision and collection of data are essential processes associated with the Virtual Ship. Data must be provided to characterise the simulated entities, their interactions and the environment. Data collection during simulation facilitates analysis and decision making.

Participation of Industry in the Virtual Ship project is essential to its success. Industry will be a significant source of models, whether the intention is to represent the force in being, or to represent future platforms in the context of capability development or acquisition.

The initial phase in establishing a Virtual Ship shall be concerned with the technical requirements associated with adopting the High Level Architecture. As the HLA is mastered attention will be focused on development of guidelines for using the Virtual Ship. An essential characteristic of the Virtual Ship is its human-in-the-loop capability. The guidelines for use will emphasise capturing the performance of trained operators in a manner that is credible in the eyes of Virtual Ship users and the decision makers who utilise its outputs. The contribution of the RAN to this process is critical.

The Virtual Ship will evolve into a dedicated facility available to support activities across the whole of the Defence Department. It will contribute significantly to research, force development, acquisition, training, mission rehearsal and tactical development.

Contents

1. Introduction

A key challenge in modern surface warfare is the integration of many different systems. These include on-board and off-board sensors, data fusion systems, command decision aids, command and control (C^2) systems, weapons and the platform itself. There is currently a gap in the capability to rigorously study these integration requirements in a laboratory environment. Additionally, the capability is lacking to comprehensively investigate the operational efficacy of new systems prior to their introduction to service.

The Virtual Ship will provide a facility through which these issues may be addressed. It will exploit modern computing capability, particularly distributed simulation technology, to bring together simulations of ship systems in order that warship operations may be simulated. The Virtual Ship will provide a human-in-the-loop capability in that human operators may interact with the simulations just as they would interact with the real system. The essential characteristic in this regard is realism. It is only through creation of a highly realistic virtual representation of a warship operations room that the Virtual Ship will attain the credibility required in order that it be used as a basis for military decision making.

The Virtual Ship will find application in support of a number of DSTO and ADF objectives. It will provide an environment within which the operational utility of sensors, signal processing techniques, data fusion techniques, command decision aids and weapon systems may be demonstrated and refined. It will enable the operational perspective to be accounted for in the laboratory, prior to expensive sea trials. It also provides a means by which system user requirements may be elicited in a controlled and cost effective manner.

The Virtual Ship will provide an environment within which integration issues may be explored and requirements determined. Prominent examples include integration of new tactical data sources, weapon systems and sensors. Particular emphasis will be placed upon operator needs in order that new capabilities are fully exploited.

The Virtual Ship will also provide an environment within which tactics and operational concepts may be explored. It is in this category of applications that the Virtual Ship will interface with operations research (OR). Operations research has traditionally been concerned with mathematical modelling and constructive simulation. Measures of effectiveness are rigorously computed, often exploiting statistical techniques. The Virtual Ship will complement this capability through the fidelity it provides and through its ability to capture human performance characteristics. The conduct of OR may produce a number of candidate tactics or concepts of operations. The high fidelity representation of warship operations provided by the Virtual Ship will allow these to be assessed and refined. Alternatively, the Virtual Ship might be used to develop initial tactics to support new systems or operational concepts. These may then be exhaustively examined using the traditional methodologies of operations research.

This collection of applications is relevant not only to the force in being, but to future concepts for the maritime force. It is clear that the Virtual Ship may form a key component within the capability development and acquisition processes. Key tasks

that must occur during these processes are requirements capture and tender assessment. Associated activities include development of tactics and training for new platforms, operational test and evaluation and through-life cost estimation. The Virtual Ship offers the potential for exploring new concepts in a rich virtual environment in which the war fighter may be immersed. There is clear potential to enhance the statement of requirement through this process. As Defence Industry makes increased use of modelling and simulation in the development and demonstration of their system capabilities, the possibility will emerge for this performance to be demonstrated within the Virtual Ship. Tendered solutions may be exercised in realistic environments against realistic representations of the threat. This offers the potential to enhance the quality of the acquisition decision.

If the provision of models within the Virtual Ship environment becomes an established part of the acquisition process then the potential exists to develop tactics and training from the time of tender acceptance and prior to platform manufacture. The platform may then enter service with crews requiring minimal at-sea training and a mature body of tactical doctrine optimised to exploit the capabilities of the new platform. The existence of the Virtual Ship will also provide a tool with which through-life support issues such as maintenance and logistical support may be investigated. This offers an enhanced capability to determine the total cost of platform ownership.

The essential components of the Virtual Ship will be system models, the data that characterise them and a federated architecture within which these models are brought together. DSTO divisions with particular expertise will be charged with developing and maintaining constituent models. The Virtual Ship will be a test bed within which they can explore new concepts within a simulated operational environment. It will thus become a focus for a wide variety of DSTO activities that support maritime operations.

Defence Industry will play a significant role in the Virtual Ship to support both the force in being and the future force through the capability development and acquisition processes. They will provide models of systems that exist in service in order that the Virtual Ship may be exploited for tactical development and studies of operational concepts. During acquisitions and upgrades they will provide models of tendered systems and these will be exercised in realistic scenarios. The ability of Defence Industry to contribute to the Virtual Ship is essential to full exploitation of the concept.

The federated architecture of the Virtual Ship will be based upon the US standard for distributed simulation, the High Level Architecture (HLA). The core of the HLA is definition of a standard for the exchange of data amongst simulations. It will be required to develop such a standard for modelling warships and their interaction with external entities. The existence of a data exchange standard enables models to be brought together in a "plug and play" fashion. An open data exchange standard also enables Industry to bring models into the Virtual Ship whilst retaining protection of their Intellectual Property, whether it be in the form of algorithms or data.

The architecture of the Virtual Ship will allow it to be rapidly configured in order to address a particular problem or application. Given an application, the requisite

models will be identified and brought together. Consider the example of anti-ship missile defence, as illustrated in Figure 1. It may be required to determine how Infrared Search and Track (IRST) might be integrated with an existing combat system in order to achieve enhanced performance in this demanding environment. For this application models are required of the above water sensors, the means by which their data is fused, the above water weapons and countermeasures available, the command and control (C^2) system, communications, vessel propulsion and vulnerability. In the context of the existing maritime force, models associated with the underwater environment are not required. The High Level Architecture (HLA) provides the technical "glue" which binds the separate models into an integrated simulation of the warship.

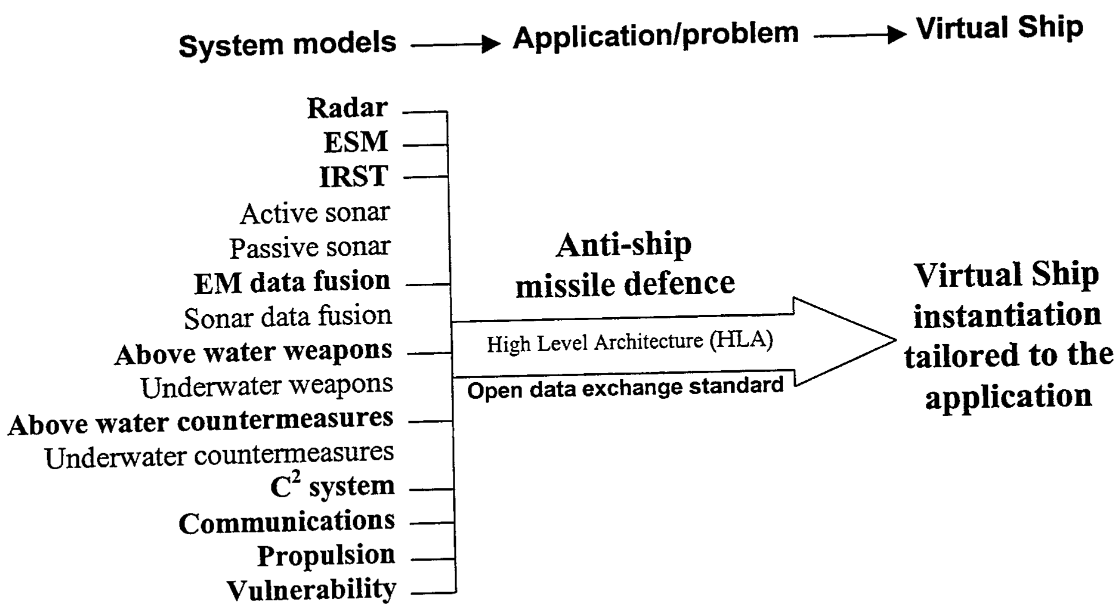

Figure 1: An illustration of how the federated Virtual Ship Architecture enables the Virtual Ship to be customised to the problem at hand. In this case it is anti-ship missile defence.

This example illustrates an essential characteristic of the Virtual Ship. It is composable to the level of complexity required to satisfy a particular objective. In some application domains, only two models may be needed in order to address a problem. In others a full simulation of warship functionality may be required to capture the rich set of interactions amongst many complex systems and the people who operate them. The ability to compose the Virtual Ship with few or many models will result in versions existing throughout DSTO and Defence Industry. Where a class of problems may be addressed completely within a given technology or warfare area, a version of the Virtual Ship may be used in which only models within this domain are brought together. These components, however, will be compatible with those from other domains and may thus be integrated to explore issues across technology and warfare areas.

The basis of the Virtual Ship upon the HLA will provide natural interoperability with virtual air and land environments, as well as those of the US and UK. The

Virtual Ship will thus provide an essential component in addressing issues of joint and coalition warfare.

This report is a contribution to the process of establishing a shared understanding of, and vision for, the Virtual Ship concept. To achieve this, section 2 describes a number of specific applications of the Virtual Ship. These range across technology and warfare areas and demonstrate the scope of the concept. Many of these applications emphasise placing humans in the simulation loop in order to understand their contribution to system performance. This consideration naturally alludes to the role the Virtual Ship may play in support of training and mission rehearsal. This is discussed in section 3.

The Virtual Ship will share a close relationship with traditional operations research. The impact of a Virtual Ship capability upon the conduct of OR is discussed in section 4, and the nature of the relationship between these capabilities is explored. The concept that unifies them is that of supporting military decision-making.

The potential role of the Virtual Ship in the acquisition process is discussed in section 5. There is particular description of the Simulation Based Acquisition (SBA) movement in the US. The objective of SBA is to integrate use of modelling and simulation with all phases of the platform acquisition process. There are two essential elements in achieving this. One is technical and concerns development of a common technical framework for modelling and simulation. This is essential in promoting re-use of simulation components across applications and in establishing common virtual environments within which competing systems may be fairly assessed. The second component of SBA concerns a process for acquisition that exploits modelling and simulation. The key concept here is the Integrated Product Team (IPT), which brings together all those with a stake in the acquisition process at the earliest stage.

The architecture of the Virtual Ship is discussed in section 6 and the relevant characteristics of the High Level Architecture are described. The Virtual Ship Architecture (VSA) consists of those components required to simulate warship operations, over and above the components of the HLA. These are presented and their characteristics described. There is also discussion of issues associated with management of the Virtual Ship and this includes computer hardware and software, security and configuration control.

The provision and collection of data are essential processes associated with the Virtual Ship. Section 7 discusses the provision of data to support simulation and the collection of data during simulation to facilitate analysis and decision making. An essential component of distributed simulation is the use of common data sources by different models. Methodologies and tools that might support this are discussed, including establishment of data standards.

The role of Industry in the Virtual Ship and mechanisms to support their participation are discussed in section 8. The way ahead for the Virtual Ship is outlined in section 9.

2. Application of the Virtual Ship - Narratives

The tasks of defining the constituent parts of the Virtual Ship, developing detailed guidelines for its use and appreciating its relationship with a range of defence activities, including research, capability development and acquisition, are assisted through development of a number of use scenarios. This section describes, in narrative form, a number of scenarios in which the Virtual Ship offers positive utility, that is it makes a positive contribution in achieving some defence objective. The examples have been chosen to reflect a range of technological issues that face maritime forces. They cover above and underwater warfare, and include specific technological issues relating to platforms and communications.

2.1 Air Defence Coordination and Cooperative Engagement Capability[1]

Anti-ship missiles pose a major threat to warships. Their speed and sea skimming capability cause two mutually enhancing problems. Their trajectory makes them difficult to detect. The late time of detection coupled with their speed requires a defensive response within a severe time constraint. A subsonic missile detected at the horizon demands a response within 80 seconds. When the missile travels at Mach 3 the time available for self-defence is 20 seconds.

The response to these demands requires optimum exploitation of technological advances in sensors, weapon systems and countermeasures. Above all else, the significant requirement is to exploit the data provided by multiple sensors and the distinctive capabilities of new weapons and countermeasures in order to implement the optimum self defence solution. The principal task of the command and control system is to provide the commander with useful information in a timely manner and the means for implementing decisions. Integration of sensor and weapon data is critical in this regard. In a heightened threat environment, failure to optimise the allocation of resources such as weapons, sensors and countermeasures could have catastrophic consequences.

High priority research is the development of enhanced algorithms for allocating weapons and countermeasures in response to the anti-ship missile threat. This is the hard kill/soft kill optimisation problem. Implicit within this program is a requirement to characterise the performance of existing and future sensors, weapons and countermeasures. Typical examples include phased array radar, the Evolved Sea Sparrow Missile (ESSM) and the NULKA active countermeasure. Performance characterisation in the context of weapon and countermeasure allocation and fire control is at the heart of the integration problem.

Once algorithms have been developed it remains to assess their operational efficacy and particularly their performance as part of a system in which a key component is the command team. It is this role that is ideally suited to the Virtual Ship. An operations room may be configured to represent in-service platforms. Models of the ship's sensors, countermeasures and weapon systems will be brought together with a

[1] This section prepared in collaboration with Dr Darren Sutton of Weapon Systems Division, Mr Grant Horsfall of Electronic Warfare Division and Dr Jonathan Legg of Surveillance Systems Division.

model of the C^2 system. Indeed, the heart of the C^2 model may be the actual system software, with a simple interface that allows its inputs and outputs to be compatible with simulated components. The algorithms developed for weapon and countermeasure allocation will be embedded within the C^2 model.

A command team will be brought together within the Virtual Ship operations room. They will conduct air warfare operations in a virtual environment that represents with high fidelity perceived threat scenarios. The threats will be provided by DSTO developed models, re-engineered to operate within the Virtual Ship simulation environment. The use of high fidelity models of the physical environment and electromagnetic propagation will permit assessment of performance within the unique conditions of our region.

This exercise will provide realism just short of actually putting a ship to sea. Indeed, the ability to realistically represent threat weapons may actually provide a benefit beyond that which can be achieved during exercises. In addition to assessing questions of platform survivability, the command team will be able to exercise their operating procedures and optimise them in a manner that exploits the capability offered by the new algorithms. The essential contribution of the human operator to the whole system may thus be accounted for in optimisation of performance and the merits of automating aspects of ship defence may be assessed.

A similar use of the Virtual Ship will support development of technological solutions that implement the new network centric warfare paradigm of air defence. Here the problem is integration of tactical data from multiple sources, and particularly the sensor data from all parts of a task force. Air defence is achieved through optimum allocation of the weapon systems and countermeasures of the whole task force. The allocation problem is greater in extent and is exacerbated by the requirement to effectively communicate tactical and intelligence data amongst multiple, and possibly remote, units. The communications aspect is highlighted in the next scenario.

2.2 Evaluation and Exploitation of Emerging Communications Technology[2]

Emerging communications technologies have the potential to revolutionise approaches to warfare. Particular attributes of this technology are high bandwidth and the ability to communicate reliably in real time across intercontinental distances. The key challenge in exploiting these attributes is integration of the communications infrastructure with an information management strategy that optimises operational effectiveness. Research is underway within Communications Division in order to meet this challenge.

The basic requirements of future network configurations have been identified in a number of reports[3,4,5]. These are:

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[2] This section prepared in collaboration with Dr Greg Simms and Mr Anthony Ween of Communications Division.

[3] Royal Australian Navy Communications and Information Systems Review (RANCIS), Phase II, RANCIS team, sponsored by Deputy Chief of Navy, 1997

1. Shore based strategic and operational sites requiring wideband communications connectivity to other land based assets.
2. Provision of high bandwidth wide area communications to mobile or deployed assets.
3. Advanced information processing and handling capabilities on board mobile or deployed assets so they can effectively utilise available communications links.

Two technical approaches to the determination of the capability improvement offered by modern communications technology are currently under consideration. One option is to integrate the physical communications infrastructure with the Virtual Ship. An alternative approach is to simulate the communications infrastructure. Either option will facilitate realistic simulation of the performance of a deployed task group utilising modern communications links. The nodes of the communications network will include instantiations of the Virtual Ship, configured to exploit the enhanced information availability. Maritime communications and information management may be observed and processes determined to evaluate capability improvements. The emphasis will be on processes and doctrine.

Particular issues that may be addressed through the Virtual Ship include:

1. Assessment of the operational effectiveness of emerging maritime services, such as the Joint Command Support Environment (JCSE). JCSE provides a situational awareness picture, data base capabilities for logistics purposes, planning aids, office automation capabilities and additional functions. In the longer term, the aim is to provide broadband, ADF wide services.

2. Evaluation of the operational effectiveness of duplex satcom links and an UHF LOS link. In the future, assessments will be made of theatre broadcast beams for high data rate, spot beam data delivery, an assortment of redundant backup links (Iridium) and emerging allied and domestic technologies.

3. Evaluation of the operational utility offered by alternative intra-ship network architectures, and particularly the provision of LANs at different classification levels. This assessment will be facilitated through integration of Virtual Ship system models, including the C^2 system, sensors and weapons.

2.3 Evaluating the Smart Ship[6]

A major trend in warship system evolution is the incorporation of reduced manning concepts as integral to the platform operation. The US Navy have trialed this on board the USS Yorktown, a Triconderoga class cruiser. Through a combination of technology initiatives, organisational change and procedural modifications, significant reduction in manpower has been achieved without a measurable reduction in platform capability.

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[4] Project Marigold Report, Maritime Command, 1995; Revised Version by Maritime Command and DSTO, 1997

[5] DSTO report SEA 1442

[6] This section prepared in collaboration with Mr Kevin Gaylor of Maritime Platforms Division.

The technology initiatives included systems such as an integrated bridge, integrated condition assessment, monitoring and control, damage control, a fibre optic LAN and a wireless voice communication system.

Research is being conducted in the Maritime Platforms Division (MPD) to examine the US Smart Ship[7] program and its follow-on developments in the surface combatant SC-21 program[8], and assess the potential benefits of some of these systems for the RAN. In addition, MPD currently has a well established research program in the areas of damage control systems and vulnerability assessment that relates directly to some of the Smart Ship initiatives.

MPD is developing a program based on a Virtual Platform which, when integrated with the Virtual Ship, will provide a capability to assess advanced platform management systems and procedures. The Virtual Platform will consist of common core information that is a combination of geometric and non-geometric engineering data describing the physical and logical configuration of the ship, and a number of models and databases relating to platform management and behaviour. These models and databases will be initially based on current MPD research areas and extend into new areas currently under development.

As an example of how the Virtual Platform will integrate with the Virtual Ship, consider the Air Defence Coordination and Cooperative Engagement Capability example outlined previously. If a missile hits the platform during a simulated engagement, the Virtual Ship can determine the extent of damage to the platform and all the systems effected. A damage management team can then exercise various damage control options to restore capability to the platform in the most effective manner, balancing requirements for damage repair time, self-protection and operational effectiveness. Various physical layouts of the platform can be exercised to determine the most effective physical and logical configuration, especially in regard to separation and redundancy of critical platform systems. The effect of reduced manning in this critical circumstance may also be assessed. Thus the Virtual Ship, together with a Virtual Platform, can be used to develop effective platform survivability strategies, both in the platform design stage and in support of the force in being.

2.4 Surface Ship Torpedo Defence[9]

Torpedoes pose a significant threat to surface ships. Advances in technology have resulted in significantly more capable and quieter torpedoes becoming available in Australia's area of strategic interest. The timely detection of these modern torpedoes over all potential directions of attack poses a significant challenge. The provision of all round coverage to a useful detection range requires the use of all available sensors, including hull mounted sonars, obstacle avoidance sonars, towed array sonars and sonobuoys. Even if the weapon is detected, suitable countermeasures need to be developed and evaluated.

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[7] http://www.dt.navy.mil/smartship/

[8] http://sc21.crane.navy.mil/

[9] This section prepared in collaboration with Mr Graeme Manzie, Dr David Kershaw and Mr Simon Taylor of Maritime Operations Division.

The use of semi-analytical models, typical of operations research, have the benefit of a small run time, and thus can be used in a Monte Carlo fashion to provide statistical measures of countermeasure effectiveness. However, these models are typically of modest fidelity and may neglect many crucial complexities, such as the actual performance of the ship's sonars and the manoeuvrability of the target platform.

The Virtual Ship will provide a welcome additional technique with which to investigate this problem. Key aspects that require investigation are the ability of the surface ship to detect the threat via a number of sensors, the ability to fuse the sensor data to potentially improve the detection range, and its ability to perform the requisite countermeasure to negate the weapon. Thus a Virtual Ship would be configured with high fidelity models of the ships sonars, integrated sonar processing and a high fidelity model of the vessel hydrodynamics and propulsion. The scenario would provide a model of the threat torpedo with a realistic representation of its dynamics and acoustic output.

Within the Virtual Ship a command team will occupy the operations room. They will detect the torpedo threat through their sonar displays and seek to implement the response as suggested by operations research. The conduct of a number of scenarios will permit assessment of three principal aspects; can the torpedo be detected sufficiently soon that countermeasures may be implemented, if so can the ship carry out the countermeasures, and if so are they effective.

The use of the Virtual Ship in this example allows investigation of the interplay between the time of threat detection and the subsequent response. This is a particularly important aspect of surface ship torpedo defence noting the improvements in torpedo technology and the increasing submarine threat in our region. This interplay cannot currently be achieved in any other way even in physical exercises since we do not possess exercise torpedoes of advanced technology (eg wake homers, quiet electric). It will allow candidate detection systems and countermeasures to be investigated in a highly realistic environment short of putting expensive ship and submarine assets to sea. The time and cost savings will be considerable.

2.5 Integrated Undersea Warfare[10]

In recognition of the threat posed by torpedoes to surface ships, there are a number of major projects currently underway, the objective of which is to enhance the Anti-Submarine Warfare (ASW) capability of surface ships. These include:

1. SEA 1100 - Australian Surface Ship Towed Array Sonar System (ASSTASS). The current phase of this project concerns evaluation of the operational effectiveness of two towed Low Frequency Active/Passive Sonars (LFAPS) to enable the ADF to become smart buyers for the next phase, in which LFAPS will be fitted to the ANZAC and FFG frigates. The system currently being evaluated is a stand-alone monostatic towed array based system that includes passive and active processing as well as a sonobuoy processor.

[10] This section prepared in collaboration with Mr Simon Taylor of Maritime Operations Division.

2. SEA 1390 - FFG Upgrade (FFGUP). This project funds a major upgrade to the weapon systems including the replacement of the hull mounted sonar with a broadband COTS based system, the addition of an obstacle avoidance sonar and a torpedo defence system.

3. SEA 1443 - ANZAC Warfighting Improvement Program (WIP). The WIP provides systems to upgrade the warfighting capability of the ANZAC frigates, including the addition of an obstacle avoidance sonar and a torpedo defence system.

4. SEA 1405 - Seahawk Midlife Upgrade (SMU). The SMU will investigate options for upgrading the capability of the organic Seahawk helicopter to ensure it provides an effective operational capability for the remainder of its life. This project will evaluate the acoustic sensors including passive and active sonobuoys, multistatic systems and dipping sonars.

Each of the above projects aims to improve the capability of surface warships by providing stand-alone sensors that operate mono-statically. There is clear potential to improve capability through the integration of data from a number of acoustic sensors, including hull mounted and towed array sonars, and sonobuoys that may be deployed directly from a warship or by its organic air assets. The term integrated undersea warfare refers to this methodology.

A significant advantage offered by integration of sonar data from multiple sensors is that of an enhanced signal-to-noise ratio. Additional advantage might be obtained through the arrangement of a bi-static or multi-static geometry amongst sonar sources, scattering targets and acoustic detectors. Such an arrangement enhances the probability that at least one of the many detectors will receive a significant echo from the target.

There are a number of challenges in implementing an integrated undersea warfare capability. The means of integrating sonar data needs be determined, as do the communications required to pass data from off-board sensors to the ship. New tactics are required to optimally exploit the technological possibilities and development of tactical aids is critical in this regard.

Although analytical studies will provide a degree of understanding of the benefits of integrated undersea warfare and recommendations for candidate tactics, a true understanding of the benefits is critically dependent upon an appreciation of the operational procedures required to implement tactics. The Virtual Ship configured with high fidelity models and operators in the loop will permit development of initial tactics and operating procedures. The appreciation of operational requirements is an essential component in the design and implementation of supporting tactical aids.

3. Training and Mission Rehearsal

The ability to replicate the operations room of platforms in service will provide a natural training facility. Particularly advantageous will be the capability to represent, with high fidelity, the threat environment, including platforms, weapons and critical physical effects, such as those associated with propagation.

The integration of models across the spectrum from the threat to the own ship combat system to the physical platform itself will enable comprehensive training of a command team. This will include mission planning, engagement with the enemy and post-engagement issues such as damage control and restoration of fighting capability.

The basis of the Virtual Ship upon distributed simulation will facilitate its connection with existing simulation based training systems in order to create more complex training scenarios. In this manner the Virtual Ship will enhance the capability being delivered by project SEA 1412. This project concerns linking existing RAN team based training simulation systems using the Distributed Interactive Simulation (DIS) protocol. The migration from DIS to HLA is a low risk exercise and it has already been demonstrated that DIS based and HLA based simulations may be directly linked. It will be possible to link multiple versions of the Virtual Ship with existing RAN systems in order to create complex multiple ship training scenarios.

Exploitation of the distributed simulation capability to operate over large geographical separations will enable a revolution in the way operations are prepared for, particularly with regard to mission rehearsal. Future systems will have training systems embedded within them which, for the most part, utilise the operational hardware and software. These embedded training systems will include scenario generators that provide the appropriate stimuli so that they may be operated realistically and thus used to derive training benefit. A distributed simulation capability will enable these stimuli to be generated by manned simulators that are remote from the operational unit, or by other operational units that are remote and utilising their embedded trainers.

These possibilities will enable units to rehearse in a common virtual operational area, despite being geographically remote. This may occur when remote units on patrol are required to marry in order to conduct an operation in response to a crisis or threat escalation. The units will be able to conduct mission rehearsal en route to the area of operations. Not only will this enable offensive action to be launched sooner, but also operational plans may be optimised through the ability to exercise them via distributed simulation.

The basis of the Virtual Ship upon the HLA will provide natural interoperability with simulation systems in the air and land domain, and those of our allies, particularly the US and UK. Virtual exercises of joint and coalition forces will be possible, as will mission rehearsal.

4. Relationship to Operations Research

As the Virtual Ship evolves its application will require new thinking as to how such a capability may be employed to support defence objectives. Consideration of its relationship with operations research offers guidance in this regard.

Operations research typically involves simulation of some military activity or operation. Many replications of the model within a common scenario are often performed, with some randomness introduced in order to replicate uncertainties in the real world. On the basis of these replications, statistical measures of effectiveness are compiled. It must also be noted that these models often encapsulate human decision making in some algorithmic form. As a consequence their output may not reflect the richness of behaviour that is evident in human systems.

A key aspect of the Virtual Ship will be its ability to put humans in the simulation loop. As a consequence these simulations will be run at, or near, real time. There are two consequences of this. The requirement to run at real time will prevent the performance of many replications of a given scenario. The presence of a human will introduce a number of effects that render any replications statistically dependent. Both these factors will militate against using the Virtual Ship to construct performance measures in the traditional way. New thinking is required as to how the Virtual Ship might best be employed.

As guidance on this issue it is important to note the essential role that operations research plays in the military context. This role is one of supporting decision making. It provides data which guides the thinking of those charged with making decisions, whether they pertain to acquisition or operational matters.

The role of the Virtual Ship will therefore be to support decision making throughout the whole of the platform lifecycle. Although the Virtual Ship may be configured without a human-in-the-loop and thus used as a traditional operations research tool, its principal contribution will be through the ability to capture human behaviour and decision making and to visualise scenarios with a high degree of realism. The data so obtained will be more qualitative than quantitative. The Virtual Ship will provide an environment within which decision makers can visualise scenarios, work through the consequences of actions and provide themselves with an enhanced capability to exercise their judgement.

The existence of such a capability will in no way diminish the role of traditional operations research. Indeed, the Virtual Ship will provide an additional tool that will both take input from, and provide input to, traditional operations research methodologies. For example, a traditional operations research approach may be applied to a problem of tactical development and, on the basis of this, several candidate tactics may be proposed. These may then be trialed in the Virtual Ship, prior to any attempt to conduct expensive sea trials. This offers a number of advantages. First, the Virtual Ship will provide a higher fidelity modelling environment and therefore provide a more rigorous assessment of the feasibility of the candidate tactics. Second, application of the Virtual Ship will allow an assessment to be made of the means by which the tactic may be implemented, that is the operational procedures required to implement it may be determined in the realistic

virtual environment. Indeed, it may be that matters concerning the human contribution to the total system may affect the ability to implement a tactic to a greater extent than the physical aspects considered in the traditional operations research approach.

The reverse process, whereby the Virtual Ship provides data for operations research, will occur when a mature and validated Virtual Ship capability exists. Certain performance parameters required for operations research are often measured using trials procedures. The Virtual Ship offers a cost effective alternative to this. The circumstance may also arise where experimentation using the Virtual Ship provides results that motivate the performance of a detailed study utilising traditional operations research techniques. It may be that a promising tactic developed in the Virtual Ship requires analysis in a range of scenarios that would be prohibitive if performed in the Virtual Ship with the human-in-the-loop. This is another example of the interplay between the Virtual Ship and operations research illustrating the enhanced capability achieved through their mutual exploitation.

5. Application to the Acquisition Process

A significant characteristic of simulation is that it may represent systems that have yet to be constructed. As a consequence, not only may the Virtual Ship represent platforms in service, it may represent concepts for future platforms. These may be exercised in realistic environments and threat scenarios in order to assess their operational utility. It is therefore evident that the Virtual Ship concept may be exploited in support of the acquisition of new maritime platforms. In order to appreciate the contribution that the Virtual Ship might make to the acquisition process it is appropriate to review the Simulation Based Acquisition (SBA) movement being led by the US.

Simulation Based Acquisition is a revolutionary approach to military acquisition. The core of SBA is exploitation of modelling and simulation throughout the acquisition process in order to field high technology systems in shorter time-scales, with reduced cost and technical risk.

There are many applications of simulation throughout the acquisition process. Simulation may be used to construct virtual concept systems and as a basis for capturing requirements. Indeed, aspects of the simulation may be used to specify the requirement. Solutions to requirements may be tendered in the form of simulations, where the systems may be assessed in virtual environments and relevant threat scenarios. The particular benefit of this approach is that the operational utility of the system may be assessed without the requirement to actually build a platform. This process will crucially engage the warfighter in the process of equipment selection.

During the design phase reviews will be facilitated through use of advanced computer aided design technologies. The physical models of old will be replaced by virtual representations in which virtual operators may interact with the system or platform in order to assess aspects like ergonomics and maintainability. It is through these aspects that logistic support requirements can be foreseen and their contribution to whole of life cost reliably estimated.

Models of ship systems will be designed to interface with computer aided design tools, or to directly use their output. In this way, a methodology is identified whereby an assessment of the operational impact of alterations in the physical design may be immediately explored. As an example, suppose a physical design option concerns the height of the mast, with a consequent impact on the height of certain sensors. Data from the relevant design tool may be fed directly into the Virtual Ship in order to explore the impact of this upon detection of above water threats, and the effect of the changed mass distribution on the hydrodynamics of the vessel.

Ultimately, an entire system will be designed in virtual form. The existence of a virtual design will facilitate the incorporation of new technology, especially that from rapidly advancing fields such as information and digital technology. This characteristic will reduce the prospect of obsolescence and reduce the risk associated with the construction of platforms. It will further enable multiple platforms of a given class to evolve as they are built, so that each comes into service with maximum technology insertion.

By the time construction begins a rich and versatile set of simulation tools describing the platform will exist. These will facilitate the immediate development and conduct of training. Tactical development may also proceed so that the introduction of the platform into service is accompanied by mature doctrine. This will considerably reduce the time from system conception to operational use that exploits all the capabilities that new technology offers.

The ability to comprehensively model the platform will also support the conduct of Operational Test and Evaluation (OT&E). Trials can be designed, with particular emphasis on determination of appropriate scenarios and data acquisition strategies. The prospect is to reduce the time required for OT&E and enhance its effectiveness.

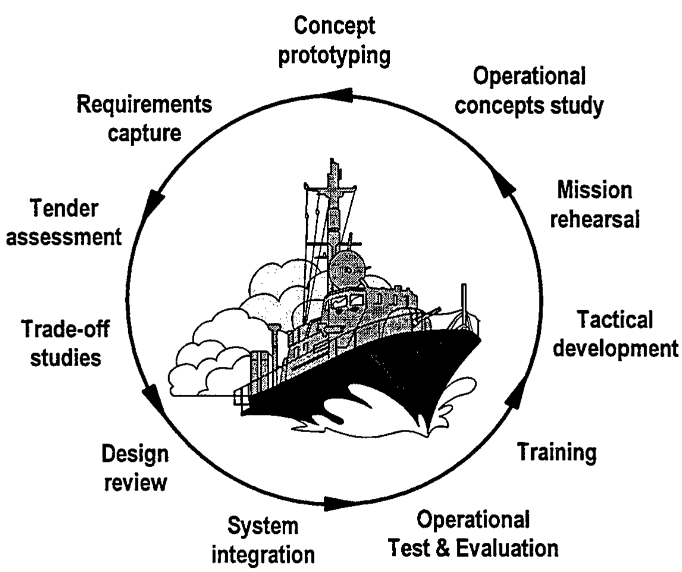

Figure 2: The Virtual Ship will support platform ownership through all phases of the lifecycle.

It is evident that the Virtual Ship will be a central component supporting all phases of the platform lifecycle. Figure 2 illustrates this concept.

There are two essential components of SBA. One aspect is a common technical framework for modelling and simulation, and this consists of the High Level Architecture (HLA), the Conceptual Model of the Mission Space[11] (CMMS) paradigm and various data standardisation activities. The second key aspect is the way that acquisition business is conducted.

The common technical framework provides the infrastructure for bringing individual simulations together to create a common virtual world. The HLA facilitates the linking of individual simulation models over a network and the exchange of information amongst them in a manner that facilitates common interpretation of it. The HLA is described in detail in section 6.

The CMMS paradigm provides a process for abstracting the essential elements required of the virtual, or synthetic, environment in order to guide their construction. Essential components are identification of the essential entities, their intrinsic behaviours and the interactions amongst them. The CMMS will provide a way of thinking about the virtual environment that is relevant both to warfighters and simulation developers. It will provide a common reference frame through which the requirements of the military user may be translated into a form that is the appropriate basis for development of a virtual environment.

The data standardisation activities particularly concern environmental data required to compute sensor and platform performance, and the visual data essential in creation of realistic virtual representations of the real world.

The new acquisition process is centred on the Integrated Product Team (IPT). These teams are composed of all stakeholders in the acquisition and include cost analysts, war fighters, designers, suppliers and manufacturers, testers and logisticians. The broad membership of these teams will enable them to better consider all issues relevant to ownership of the platform/system throughout its whole life. These teams will be supported in their analysis by modelling and simulation. Solutions to requirements will be provided in virtual form and assembled into a virtual prototype of the whole system. The common technical framework for modelling and simulation will facilitate this. As this process evolves the customer and supplier will acquire complete validated knowledge of the model upon which to make minimal risk decisions in proceeding to production.

In order to contribute to this new paradigm for acquisition, the key technical challenge is to establish the common technical framework within DSTO and Defence Industry. In addition, there will be a requirement to contribute models that encapsulate information and data that is held by the Commonwealth and which will make an essential contribution to tender assessment. Finally, there will be a requirement for advice on the conduct of technical assessments. The existence of virtual prototypes, that allow solutions to be exercised by humans in realistic

[11] http://hla.dmso.mil/projects/cmms/

environments and scenarios, will require new methodologies for measuring effectiveness. The technical community will drive this process.

The Virtual Ship has significant potential to contribute to an evolution of acquisition practice in the maritime domain. The core technology being adopted by the Virtual Ship project is the High Level Architecture. The Virtual Ship project will facilitate adoption of this core component of the US common technical framework by Australian Defence Industry. The Virtual Ship project will establish the specific technical requirements for this to be applied to maritime simulation and hence acquisition. The Virtual Ship project will develop methodologies for exploiting the capability to comprehensively simulate warship operations and particularly measuring effectiveness. In collaboration with the acquisition community, the Virtual Ship project will be able to provide guidance as to how the acquisition process might exploit the Virtual Ship to enhance platform effectiveness, reduce the risks associated with acquisition and ownership, and reduce the total cost of ownership.

The Virtual Ship might be used in support of an acquisition as follows. Suppose an operational need above that satisfied by existing capabilities is identified. The existence of a collection of system models will be brought together in order to explore concepts for a platform that provides the solution to the requirement. The particular advantage that a Virtual Ship capability will offer is that of immersing the war fighter in the virtual environment. Apart from traditional analysis and compilation of numerical measures of effectiveness, this will enable human interaction characteristics to be assessed.

As concepts are explored the formal requirement for the platform will evolve. The constituent models of the Virtual Ship will be those that represent existing or prototype systems. For example, models of concept radar systems may be incorporated and the operational performance compared with that provided by current systems. These assessments will be made by exercising the Virtual Ship in operationally relevant scenarios. A key contribution that DSTO will make in this regard is through provision of an appropriate threat scenario that exhibits the true performance of threat weapons and platforms.

It is apparent that the processes of capturing requirements and demonstrating potential solutions (tender assessment) will become enmeshed and less distinct. This will require new processes for acquisition and a detailed discussion of this is beyond the scope of this report. However, the use of virtual prototypes will ensure that when the decision is made to proceed to construct the platform many risks will have been identified and minimised and maximum mature technology insertion will be achieved.

The existence of a Virtual Ship will enable the platform to continually evolve in virtual form. This will consist of replacement of system models as new ones become available which demonstrate enhanced capability. Essentially, at all stages throughout the life of the platform, a Virtual Ship may exist that differs from the actual platform in that it represents the capability if the most recent technology were exploited. It may be considered that the existence of a Virtual Ship will enable the creation of a living design that evolves with technology. At given points in time this will enable upgrades of the physical platform to take place seamlessly, and prevent the obsolescence of platforms required in service.

To fully exploit the Virtual Ship in support of platform ownership at all stages of the lifecycle requires adoption of the concept by all stakeholders. In the context of acquisition, the process must evolve to exploit the distinctive capability of a virtual platform to visualise solutions to requirements and exercise them in operationally relevant scenarios. This process must proceed in partnership with development of the technical framework that enables it. This will allow all opportunities for exploitation to be identified and will ensure that technical activities address the array of commercial issues that confront acquisition organisations. In addition to the partnership required between the acquisition and technical communities is a partnership with Industry. The technical aspects of this relationship are discussed in the context of the Virtual Ship in section 7.

6. Architecture

6.1 General Requirements for the Virtual Ship Architecture

The Virtual Ship Architecture will provide the framework enabling system models to be brought together to simulate warship operations. To achieve this the Virtual Ship Architecture requires a number of features. It must have a modular structure in order that components can be reused and applied across a range of applications. The architecture must be open so that the capabilities of many participants may be utilised. The architecture must support integration of models of varying degrees of fidelity, which will be mapped to applications. The architecture must support use of models both for analysis and for real time human-in-the-loop applications. Models used for analysis will typically be run many times in order to compile statistically relevant measures of effectiveness. Their essential characteristics are execution speed constrained only by computer processor power, and repeatability under circumstances of identical initial conditions and inputs.

The Virtual Ship architecture must support a degree of hardware heterogeneity. For example, it is appropriate that simulations may be hosted on PC's or workstations running various versions of the UNIX operating system. The architecture should also support simulations constructed in a variety of programming languages. The underlying architecture should be supportable into the future and have scope to accommodate models obtained from other nations through various exchange mechanisms. The Virtual Ship Architecture is also required to support distributed simulation. When a mature capability exists to comprehensively simulate warship operations it will be possible to exercise together multiple instances of the Virtual Ship. The scope also exists to exercise the Virtual Ship with and against similar virtual platforms under development in other nations, or those developed in the air and land domains.

6.2 The High Level Architecture - HLA

In consideration of these factors, and particularly trends in modelling and simulation in the US, it is appropriate to exploit the High Level Architecture[12] (HLA) as the basis

[12] http://hla.dmso.mil

for the Virtual Ship Architecture. The essence of the HLA is as follows. The HLA supports distributed simulation and supersedes both the DIS protocol and the Aggregate Level Simulation Protocol (ALSP). It facilitates the connection of simulations over some network and provides the mechanisms by which they exchange information about the entities they model, send and receive interactions and co-ordinate their time advance. In the terminology of the HLA, individual simulation models are known as federates. The collection of federates brought together to simulate a complex environment is known as a federation. It is through the common interpretation of shared data that the federates interact within a single virtual environment.

There are three components of the HLA. These are the rules[13], the Object Model Template[14] (OMT) and the interface specification[15]. The rules mandate certain characteristics of models brought together under the HLA. The key objective in mandating certain characteristics in rules is to ensure that models are re-useable across applications.

The data exchanged by the federates are arranged in an object model and classified according to whether the data describe persistent entities or transient events. Persistent entities are known as objects and each is described by a set of attributes. Transient events are known as interactions and are described by a set of parameters. The format of this object model is given by the OMT. Each federate is described by a Simulation Object Model (SOM) which is constructed in the format of the OMT. The SOM details the object attributes that this federate either provides or receives information about. It also details the interactions that this federate initiates or receives.

All the data exchanged amongst the collection of federates is described by the Federation Object Model (FOM). The FOM describes all objects within the federation and all attributes that describe them. It also describes all interactions that occur within the federation. The FOM is essentially a superset of the SOM's and is constructed according to the OMT. It can be viewed as the data exchange contract amongst federates. If the FOM is considered as a standard for a particular simulation application then all models engineered to this standard will have the necessary basic functionality to operate together.

The HLA interface specification describes the means by which federates interact with the underlying data transport mechanism, known as the Run Time Infrastructure (RTI). The RTI provides six service sets. These enable management of the federation, the exchange of data amongst the federates and the co-ordination of their time.

The federates exchange information via the RTI through the processes of publication and subscription. Federates that own object attributes publish updates of their values. Federates that wish to receive attribute updates subscribe to these attributes. Hence, when a federate publishes a new value of an attribute this is passed by the RTI to all other federates than have subscribed to this attribute. Federates also publish and subscribe interactions.

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[13] http://hla.dmso.mil/hla/tech/rules/

[14] http://hla.dmso.mil/hla/tech/omtspec/

[15] http://hla.dmso.mil/hla/tech/ifspec/

As described above, the publication and subscription functions exploit two sets of services provided by the RTI. These are the declaration management and object management services. The full collection of services is as follows:

Federation management,
Declaration management,
Object management,
Ownership management,
Time management,
Data distribution management.

The federation management services provide the means to create and destroy federation executions, pause and restart federation executions, save the state of a federation and restore a saved state.

The declaration management services provide the means by which federates advise the RTI as to which object attributes they wish to publish and subscribe to, and similarly with respect to interactions.

The object management services provide the means by which federates send and receive attribute updates, send and receive interactions and alter the transportation and ordering properties of these updates.

The ownership management services provide the means by which ownership of attributes may be transferred amongst the federates. This provides a very powerful capability. A federate that owns an attribute has responsibility for providing updates of it. The ownership management services provide the means by which this responsibility is vested in the most capable federate. A consequence is that a single physical object represented within a federate, such a ship, may have ownership of its attributes distributed amongst a number of federates.

The time management services provide the means by which federates advance their time, and particularly the means by which they co-ordinate their time advances. These services support both DIS-like and ALSP-type time management approaches. In DIS there is no common time and each of the federates advances its time according to a local clock. In ALSP-type federations the federates must co-ordinate their time advances and particularly preserve causality through delivery of messages in time stamp order.

The data distribution services provide the means by which routing spaces may be created in order to more efficiently transport attribute updates and interactions over the network.

The software that implements the interface specification is also referred to as the RTI and the application developer makes use of it through the Application Programmers Interface (API). DMSO has sponsored development of an RTI and API's are currently available in C++, Ada 95, CORBA IDL and JAVA. There are two parts of the interface to the RTI. These are the RTI Ambassador and the Federate Ambassador. The RTI Ambassador is a library that is linked into each federate and facilitates communication from the federate to the RTI. The Federate Ambassador facilitates

communication from the RTI to the federate. Although the interface to the Federate Ambassador is mandated, the simulation developer must construct the internal details in order to implement the appropriate response to messages from the RTI. As an example, when a federate is required to issue an attribute update this is achieved through a call to an RTI Ambassador procedure. When this attribute update is received at another federate, the RTI Ambassador at this federate makes a call-back to the appropriate Federate Ambassador procedure.

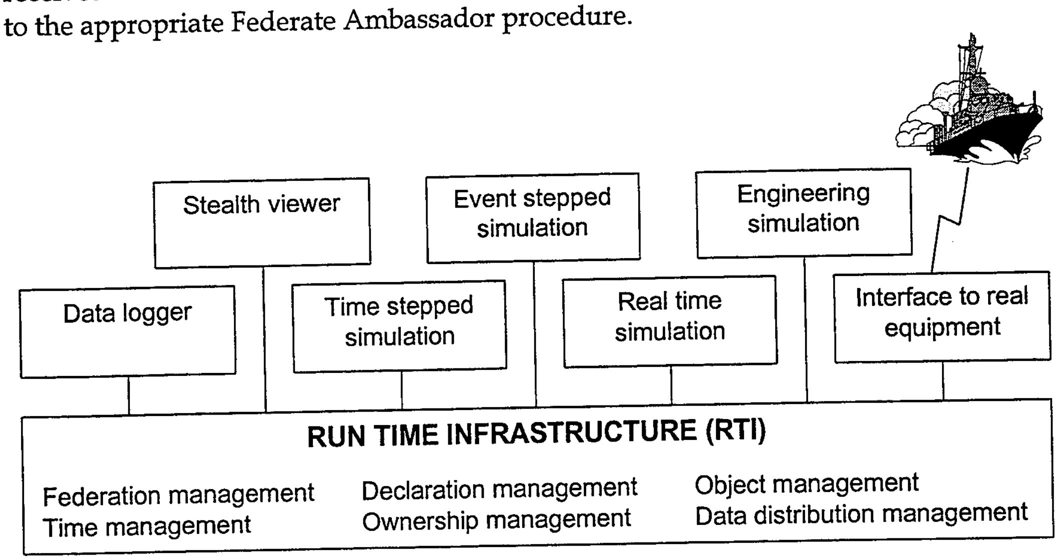

Figure 3: A functional view of the HLA. Many different types of federates may operate together over a network. The RTI provides the services that facilitate transfer of data amongst federates and the co-ordination of their time advances.

A functional view of the HLA is shown in Figure 3. A number of federates may be brought together to create a common virtual, or synthetic, environment. Some of these may be passive, such as data loggers and stealth viewers. These merely receive data transmitted over the network and analyse or visualise it. The HLA enables event-stepped and time-stepped federates to operate together and co-ordinates their time advances. Real time simulations may participate in the federation, as may real equipment through an appropriate interface. Engineering simulations, usually based upon the laws of physics, may also be integrated into the federation execution. It is this capability that will enable computer aided design tools to be an integral part of the Virtual Ship.

It is appropriate to make comment concerning those aspects of the HLA that make it the appropriate basis for the Virtual Ship Architecture. The FOM is used to configure the RTI to facilitate data exchange in accordance with it. Thus the federation developer may determine the data exchange format through design of the FOM. This offers considerable flexibility in optimising the data exchange for the application at hand.

The HLA has been declared as the standard for distributed simulation in the US. Indeed, as of FY01 any non-HLA compliant simulations will be retired from use unless an exemption is granted[16]. In addition NATO has recently proposed HLA as

[16] http://hla.dmso.mil/hla/policy/kaminski.html

the technical standard for distributed simulation[17]. There are two consequences of this. A great deal of effort is being expended in the US and elsewhere on development of tools that support distributed simulation under the HLA. These include object model development tools, standard libraries and lexicons, data standards and automatic code development tools. The availability of these will enhance simulation developers capacity to produce HLA compliant federates. The second consequence is that any models obtained from the US, and potentially other nations, will be HLA compliant and therefore more easily integrated into a Virtual Ship environment based on the HLA.

The HLA services offer considerable advantages compared with other distributed simulation technologies. The exchange of data, whether this be through attribute updates or interactions, is facilitated through processes of subscription and publication. Federates publish the attributes of the objects they own, and only provide updates of these when they change. This contrasts with the DIS where protocol data units (PDU's) are transmitted over the network which contain mandated data components, irrespective of whether the data has changed or not since it was last transmitted. Similarly, federates subscribe to only the data they require. This approach has the potential to reduce network bandwidth requirements and enhance the scalability of federations.

A most powerful aspect of the HLA is its time management service set and the ability it offers to bring together simulations that advance time in different ways. HLA supports real time applications, such as those that derive from the DIS community. These federates typically advance their time according to a local clock and interactions and attribute updates occur when the relevant packets of data are received, or at a time attached to them. HLA also supports federates that require delivery of messages in time stamp order and require co-ordinated time advance. These applications are typically used in analysis applications and are often run many times in order to compile statistically relevant measures of effectiveness. An essential requirement for these models is that causality is strictly preserved and that simulation runs are reproducible when provided with the same initial conditions and inputs throughout execution. HLA supports delivery of messages in time stamp order and provides mechanisms through which the time advance of federates may be coordinated. It provides mechanisms by which time stepped, event stepped and real time federates may operate together and coordinate their time advances.

The ownership management services provide the means by which the responsibility to update attributes, otherwise referred to as the ownership of attributes, may be exchanged amongst federates. This capability may be exploited in a number of ways. The ownership of objects and attributes may be transferred amongst a number of federates in order to distribute the computational load. The ownership of attributes may be transferred to specialised federates in order to provide a higher fidelity representation. An example of this is the radar cross section of an entity. This may be simply described by a single number. However, it may be desired to use a high fidelity model that determines the cross section as a function of the aspect of the entity. A dedicated model may provide such a capability and ownership of this attribute will therefore be transferred to it. Another notable application of this capability is in modelling short time scale interactions. An example is the end game

[17] http://www.dmso.mil/dmso/docslib/mspolicy/nato_msmp/

encounter between an anti-ship missile and a ship. The circumstance may arise that network latency prevents the timely exchange of data between the federates representing the ship and missile and therefore renders the simulation unrealistic. A potential solution is to transfer ownership of the missile to the federate modelling the ship so that the encounter is modelled within a single federate.

A final distinctive capability offered by the HLA is through its data distribution management services. This enables the definition of regions of interest, within which federates may express the desire to receive certain data. An example of this is a geographic region of interest. If a federate models a ship and the sonars on board, as far as modelling these is concerned it may be deemed that the federate requires data concerning other entities within a 30km radius of it, say. A region of interest around the ship may be defined and the federate modelling the ship will only receive data concerning other entities within this region. This service therefore provides an additional means by which network traffic is reduced. The definition of regions of interest for data distribution may more generally used to impose a filter on the delivery of data to certain federates.

6.3 Elements of the Virtual Ship Architecture

The Virtual Ship will be constructed in accordance with the High Level Architecture. In addition, the specific objective of simulating warship operations necessitates addition to, or specialisation of, the HLA. This collection of additions and specialisations will constitute the Virtual Ship Architecture (VSA).

There will be five essential elements of the VSA. These are described as follows.

The Virtual Ship Federation Object Model - VS-FOM

The VS-FOM will define the data exchange standard for those federates that constitute the Virtual Ship. It will be constructed in accordance with the Object Model Template (OMT). The VS-FOM will exploit class hierarchies in order to support federates of differing fidelity. The VS-FOM will be constructed in such a manner that it readily enables the incorporation of additional object and interaction classes.

The Virtual Ship Lexicon

The objects, attributes, interactions and parameters within the VS-FOM will form the Virtual Ship lexicon. The lexicon will provide for common terminology use across modelling applications. It is through the common interpretation of data that a common world view can be established amongst distributed federates.

The Virtual Ship Rules

The Virtual Ship rules will describe mandatory characteristics of federates brought into the Virtual Ship, over and above the HLA rules.

Virtual Ship Data Standards

Different modelling applications relevant to the Virtual Ship have shared interest in data. The provision and exploitation of this data will be facilitated through establishment of common data standards.

The Virtual Ship Tools

A variety of existing tools will support development of the Virtual Ship. In addition to tools that support the HLA generally, a requirement for additional tools can be foreseen. These will support federate development, object model consistency checking, federate monitoring including stealth viewing and federation execution management and analysis.

6.4 Aspects Related to the Architecture

The architecture of the Virtual Ship is independent of its implementation. However it is only through implementation of the Virtual Ship concept that applications may be addressed and benefit derived. To this end a range of additional issues must be explored and some of these are detailed in the following.

Software

A number of software components will be utilised in construction of the Virtual Ship. The HLA RTI will provide the underlying mechanism for data exchange amongst models. Initially it is appropriate to exploit that provided by DMSO. As time passes commercial implementations of the RTI will become available. It is anticipated that what will differentiate one RTI form another will be the type of simulation application for which its performance is optimised. For example, some RTI's may be optimised for DIS-like real time operation[18] whereas others may be optimised for analysis type operations. Given that the HLA interface is mandated, there will be no technical implications in moving from one RTI to another, apart from recompilation of federates.

The language in which federates are developed is essentially irrelevant, as long as a mechanism is available by which the federate may invoke the RTI API. At present API's are available in C++, JAVA, CORBA IDL and ADA 95. It is anticipated that most federates will be constructed in these languages or wrapped in them. A particular challenge will be to bring legacy simulations to compliance with the Virtual Ship Architecture. A class of these is physics based models typically written in FORTRAN. A variety of novel techniques will be required to construct wrappers that implement a distributed simulation capability.

Hardware

As with software it is intended to support simulation implementations on a range of common computational platforms. This particularly includes PC's and workstations running varieties of the UNIX operating system. The availability of RTI software for

[18] Such an RTI has recently been introduced to the market by MäK Technologies.

a range of platforms will facilitate this. The DMSO RTI currently supports the following hardware: SGI, HP, Sun, PC (Windows NT), DEC Alpha.

Security

It is intended that the Virtual Ship Architecture, and particularly the VS-FOM and Virtual Ship lexicon, will be unclassified. The models and data required to instantiate the Virtual Ship will be classified by the model and data owner. The classification of particular instantiations of the Virtual Ship will be determined by the highest classification of constituent parts. In general, it is anticipated that classified instantiations will exist in a secure environment. In the event that classified components are remote, encryption of network traffic will be required. The impact of this on the performance of distributed simulation is not fully known and will be a subject for investigation.

Software development standards

It will be required to adopt a standard for software development in the Virtual Ship project. The objective of adopting a standard is to ensure that models have been correctly implemented, to provide a functional description of components to other participants in the Virtual Ship and to enable rapid integration through the availability of appropriate documentation.

It is anticipated that, as a minimum, software components will be supported by a functional specification, a detailed design document and a user guide. A test specification and record of testing should also be available. It may be required to waive some of these requirements in the case of legacy code, however this is expected to be an extreme circumstance.

In order to facilitate rapid integration and re-use it is anticipated that software will be modular and may adhere to an object-oriented methodology, although these requirements are recommendations only. The development of class libraries may contribute to re-use. This may be particularly so in the area of HCI displays.

As the Virtual Ship concept evolves, detailed recommendations concerning software development standards will be developed and promulgated.

Configuration control

All components of the Virtual Ship shall be subject to change control. This includes the constituent models, the architecture, requisite data and federations.

With development of the architecture, a baseline standard will be designated as Version 1. Change control will be mandatory after declaration of this baseline. Change control of individual federates will be the responsibility of the federate custodian. Details of federate version numbers will be an essential component of federation change control, and will be a requirement for participation in an execution of the Virtual Ship federation.

7. Data

The exchange and common interpretation of data is the foundation of distributed simulation. Within the High Level Architecture the data exchanged is structured using the Object Model Template and the content standardised through use of a common lexicon. Development of the Virtual Ship Architecture will establish a lexicon for use in simulating warship operations. More generally, the Object Model Data Dictionary[19] developed by DMSO is an attempt to provide a common lexicon for use in distributed simulation applications.

A number of other issues pertaining to data are raised in this section. There is a requirement for common access to authoritative data sources in order to establish a realistic common world view. There is a requirement to identify common data requirements across applications and standardise these. The availability of experimental and trials data is essential for model validation. This is a critical exercise in order to establish the credibility of the Virtual Ship as a tool for exploring a wide variety of issues in maritime operations. Finally, large quantities of data may be gathered during federation executions. This offers considerable scope for replaying virtual exercises to support training, mission rehearsal and tactical development. Analysis functions may be embedded within the federation and the quantity of data available poses a considerable challenge in optimising the analysis methodology.

7.1 Common Access to Authoritative Data Sources

In addition to exchanging data, distributed simulation applications have a requirement to access large bodies of data that describe the physical environment. These data may permit computation of sound and electromagnetic propagation, or they may enable the creation of a highly realistic visual representation of a scenario. Although such data could conceivably be exchanged amongst federates, the sheer volume of it precludes this on practical grounds. The appropriate solution is for individual federates to access the data directly, with commonality of use achieved through a shared reference to the data.

Particular initiatives concerned with facilitating common access to authoritative data sources are the Master Environment Library[20] (MEL) and Synthetic Environment Data Representation and Interchange Specification[21] (SEDRIS) projects. These are core components of the common technical framework for modelling and simulation being pursued by DMSO. Both may be exploited in establishing and using the Virtual Ship.

The MEL is an online catalogue of environmental data sources. A user may identify data that satisfies a requirement and order the data online. It provides a single point through which users may access a large collection of authoritative data sources. SEDRIS is concerned with defining a standard data format for environmental data as used in synthetic environments. Its scope includes both visual data and data required

[19] http://s3.arlut.utexas.edu/omdds/code/index.htm

[20] http://mel.dmso.mil

[21] http://www.sedris.org

to determine propagation of sound and electromagnetic radiation. A number of API's are being developed for converting between the SEDRIS format and proprietary data formats.

In addition to exploiting these US initiatives, there will be a requirement to determine authoritative sources of data to support the Virtual Ship. These data will describe sensors, weapons and C^2 systems. It will be required to establish the means of access to relevant data, along with the responsibility for accuracy and management of data components.

7.2 Identification and Standardisation of Common Data Requirements

There are many mature applications of modelling and simulation in the maritime domain. These have traditionally operated independently of one another and the challenge is to bring them together in the Virtual Ship project. As this process occurs it is anticipated that common requirements for data will be identified. This process will drive the establishment of data standards so that additional sources of authoritative data may be made available.

A typical area in which common data is required concerns the platform itself. A significant capability exists to model the hydrodynamics of warships and this requires detailed information concerning the hull shape and distribution of mass in the vessel. Another well developed area is that of damage modelling. These models require detailed descriptions of the vessel construction, including the layout and connectivity of compartments and the distribution of equipment throughout the vessel. The requirement for vessel construction data is common, yet different sources are used for each application. There is clear scope for developing a common format for the required data.

The development of data standards will provide considerable benefits beyond economising the effort in data collection. Aspects of future concepts for platforms may be specified in terms of standard data formats. This will enable the suite of simulations that constitute the Virtual Ship to be applied to investigate a range of performance issues relating to the new platform. During an acquisition, potential suppliers may provide data concerning their solutions in standard formats. Again the simulation tools of the Virtual Ship may be immediately applied in order to acquire a detailed appreciation of the capabilities of the system offered.

7.3 Data Required to Validate Models

The Virtual Ship offers the capability to simulate environments and circumstances beyond those that can be achieved in exercises and trials. In order that these simulated scenarios are credible with users of the Virtual Ship it is essential that it be validated through comparison with available data. As a consequence of this requirement it is essential that validation data is gathered and archived. At a low level is the requirement for physics based experimental data with which models of sensors may be validated. At a higher level is a requirement for data concerning the outcome of exercises and trials, where higher order performance measures are

recorded. These data will be used to validate instantiations of the Virtual Ship and the methodology for bringing models together.

An essential requirement during the acquisition process is to gather data to validate models developed specifically to support the acquisition. This may require the construction of prototypes or subsystem components. The intention is to provide sufficient data so that a required degree of confidence in the modelling solution is acquired.

7.4 Data Gathering During Federation Execution

The conduct of simulation offers the capability to embed data gathering functions within the models. In the context of a distributed simulation, data may be gathered within individual federates and may also be gathered from the network. In the recent Synthetic Theatre of War (STOW)[22] demonstration in October 1997 a number of tools were developed to gather the data shared amongst a collection of federates[23]. In particular, the Common Data Infrastructure (CDI) gathered data in a distributed fashion and stored it in an Oracle database. An advantage that the HLA offers in automated collection of data is that the federation execution data (FED) file documents the object and interaction class hierarchies and may be used to automatically configure the database. This particular application of embedded data gathering was to provide a post exercise replay facility in support of a computer aided exercise. The term after action review (AAR) is also used to describe this process. Te capability to replay virtual exercises will make a critical contribution to training, mission rehearsal and tactical development.

It is evident that data may also be gathered to support an analysis application or decision making process. Key performance measures, such as detection ranges, may be recorded. In addition, records of events internal to federates may be compiled and correlated with each other in order to identify dependencies and causalities. It is through this capability to embed data gathering that the Virtual Ship will provide maximum utility in supporting decision making.

A difficulty evident in performing AAR in support of the STOW program was the extraction of meaningful data and performance measures from all the data gathered throughout a federation execution. This difficulty is also evident in the context of the analysis application. The challenge is to embed analysis functions within the federation so that analysis is performed whilst the federation execution is underway. The objective is to reduce the amount of data collected and stored, and to provide meaningful data in a timely manner. The quantity of data that may be generated during large simulation executions is too large to facilitate rapid analysis after the event.

[22] http://stow98.spawar.navy.mil/

[23] Kanewske, C. & Fine, S. (1998) *STOW systems integration, tools and applications.* Spring 1998 Simulation Interoperability Workshop, Orlando, Florida. Paper 98S-SIW-110. Available at http://siso.sc.ist.ucf.edu/siw/98Spring/view-papers.htm

8. Industry Participation

Engaging Industry in the Virtual Ship program is an essential prerequisite for the concept to achieve its vision of supporting platform ownership throughout all phases of the lifecycle. To create representations of the force in being requires models of existing systems. For the most part, these are appropriately provided by the system suppliers. To create representations of future platforms, whether during concept exploration or acquisition, requires models of future systems. Again the ideal solution is for these models to be provided by Industry.

A principal advantage of the Virtual Ship concept is the ability to exercise in realistic environments against realistic threats. The creation of the unique environments and threat scenarios relevant to Australia's strategic circumstances will be a principal task for DSTO. The capability is therefore required to effectively integrate models provided by Industry with models provided by DSTO.

There are a number of requirements in creating the circumstances whereby Industry models are readily integrated within the Virtual Ship. Exploiting the HLA imposes technical demands. In addition, Industry must be confident that the integration process allows the performance of the modelled system to be adequately demonstrated. Industry must also be satisfied that bringing simulations into the Virtual Ship federation will not compromise their Intellectual Property Rights (IPR).

The solution to these requirements is to engage Industry in development of the Virtual Ship Architecture and to provide a high degree of transparency in the way the Virtual Ship is used.

Engaging Industry in development of the Virtual Ship Architecture will ensure that the Industry perspective is accommodated in its formulation. It will also ensure that Industry has an intimate knowledge of the VSA and is therefore able to engineer models so that they may be integrated into the Virtual Ship. As the VSA evolves it will be exercised using simple and generic models. Industry will be invited to participate in these demonstrations in order that they may acquire practical experience of integrating models using the HLA.

Use of the HLA and a standard data exchange format as embodied in the VS-FOM provides a mechanism through which multiple Industry participants may bring models to a single federation. The type of data exchanged is open, but the actual data exchanged is at the discretion of the model custodian. Under some circumstances it may be appropriate that true performance data is exchanged. An example of this might be where models from a single company are joined with Commonwealth owned models in order to make some assessment of system performance in a realistic threat environment in the context of an acquisition. Under other circumstances, models from a number of Industry sources may be brought together and only generic data is exchanged.

The notable feature of adopting HLA is that federate custodians determine the data exchanged. In addition, any data internal to the model and details of algorithms remain encapsulated within the simulation. This offers a degree of protection to proprietry data and algorithms.

As the technology required to implement the Virtual Ship is mastered, the emphasis of the program will be directed towards development of methodologies for using the Virtual Ship to support decision making. In the context of the acquisition process these will be critical and it is essential that the methodologies pursued facilitate a fair assessment of competing solutions. To establish an appreciation of this characteristic, Industry must be engaged in development, and exercising, of methodologies for using the Virtual Ship. This will cover not only the mechanics of the process, but also the question of performance measures in a simulation which has intrinsic variability due to the human component and which cannot be repeated sufficiently to compile traditional statistical measures of effectiveness.

9. The Way Forward

The Virtual Ship concept has the potential to provide a new and significant capability to support maritime platform ownership throughout the whole lifecycle. There are a number of particular characteristics that underlie this potential. The ability to create a realistic virtual environment within which to immerse human operators will enable the complex interactions that define the command and control of a maritime platform to be investigated and appreciated. The ability to integrate virtual representations of current and emerging systems will enhance decision-makers understanding of their problem domain. This aspect is equally applicable to capability development, acquisition, tactical development and mission rehearsal. In the particular case of acquisition, the use of a Virtual Ship to exercise proposed solutions to requirements has the potential to reduce the risk, particularly associated with system integration. It also has the potential to reduce the time required to acquire and effectively employ new platforms.

The development of a Virtual Ship capability will demand new thinking concerning the way in which such a capability is exploited to facilitate military decision making. A particular aspect will be the relationship between the Virtual Ship and the traditional methods of operations research. The rigorous statistical techniques of operations research are not appropriate in an environment where there is significant variation due to human performance and in which few replications of scenarios are available. The solution may be to use operations research techniques to reduce the number of scenarios that need be investigated in high fidelity representations of the Virtual Ship. Alternatively, approaches suggested through exercising the Virtual Ship might form the subject of detailed operations research studies.

There are a number of threads of activity that will bring the Virtual Ship vision to fruition. The Virtual Ship Architecture Working Group (VSAWG) has been established to develop and evolve the Virtual Ship Architecture. Although the activities of the VSAWG will address each of the elements of the VSA, the principal focus will be upon determination of the standard for data exchange amongst models, otherwise known as the VS-FOM. A parallel thread of activity will seek to demonstrate use of this data standard through the conduct of technical demonstrations. It is anticipated that the outcomes of these demonstrations will feedback to evolve the data exchange standard.

Industry will be engaged in the process of determining the VSA through an invitation to participate in the VSAWG. In addition, Industry will be invited to participate in technical demonstrations. This will allow the Industry perspective to be incorporated within the VSA. Industry will acquire the intimate knowledge of the VSA required to engineer models in accordance with it. They will also establish a core of expertise in the High Level Architecture.

As the VS-FOM becomes stable it will form the backbone through which models may be brought together in order to simulate aspects of warship operations. It will be appropriate to review legacy models within DSTO and re-engineer them to compliance with the VSA. Indeed, a critical contribution that DSTO will make to the Virtual Ship is the ability to represent the threat environment. Models that contribute to this will be brought to compliance with the VSA as a matter of priority. It will be appropriate to review research programs in order to identify those aspects that might profitably be used as a basis for VSA compliant models. It is anticipated that parallel activity will occur in Industry, so that they may demonstrate and exercise the capability of their systems in the Virtual Ship environment.

During this review process the data required for models will be considered and common requirements identified. This will provide the impetus for development of data standards across applications. Alternatively, a requirement may be identified for tools that transform common data amongst a variety of related formats. It is through identification of common data requirements that the Virtual Ship will be able to provide support to a platform from the earliest stages. The availability of data in common formats will facilitate application of modelling and simulation prior to the platform existing.

As a suite of models compliant with the VSA is developed, methodologies for managing them will be developed, as will methodologies for effectively integrating them in support of specific applications. Guidelines will be developed for exploiting the Virtual Ship in support of decision making, whether this is associated with acquisition or operational matters. A suite of tools will be available that assist in configuration of the Virtual Ship and in data compilation and analysis.

An essential characterisitic of the Virtual Ship is its human-in-the-loop capability. The guidelines for its use will emphasise capturing the performance of trained RAN operators in a manner that is credible in the eyes of Virtual Ship users and the decision makers who utilise its outputs. The contribution of the RAN to this process is critical.

The Virtual Ship will evolve into a dedicated facility available to support activities across the whole of the Defence Department. It will contribute significantly to force development, acquisition, training, mission rehearsal and tactical development.

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11. List of Acronyms

AAR	After Action Review
ADF	Australian Defence Force
ALSP	Aggregate Level Simulation Protocol
API	Application Programmers Interface
ASSTASS	Australian Surface Ship Towed Array Sonar System
ASW	Anti-Submarine Warfare
C^2	Command and Control
CDI	Common Data Infrastructure
CMMS	Conceptual Models of the Mission Space
COTS	Commercial Off The Shelf
DERA	Defence Evaluation and Research Agency
DIS	Distributed Interactive Simulation
DMSO	Defense Modelling and Simulation Office
DSTO	Defence Science and Technology Organisation
ESSM	Evolved Sea Sparrow Missile
FED	Federation Execution Data
FFGUP	FFG Upgrade Project
FOM	Federation Object Model
FY	Financial Year
HLA	High Level Architecture
IPR	Intellectual Property Rights
IPT	Integrated Product Team
IRST	Infrared Search and Track
JCSE	Joint Command Support Environment
LAN	Local Area Network
LFAPS	Low Frequency Active/Passive Sonars
LOS	Line Of Sight
MEL	Master Environment Library
MPD	Maritime Platforms Division
NATO	North Atlantic Treaty Organisation
OMT	Object Model Template
OR	Operations Research
OT&E	Operational Test and Evaluation
PC	Personal Computer
PDU	Protocol Data Unit
RAN	Royal Australian Navy
RTI	Run Time Infrastructure
SBA	Simulation Based Acquisition

SEDRIS	Synthetic Environment Data Representation and Interchange Specification
SMU	Seahawk Midlife Upgrade
SOM	Simulation Object Model
STOW	Synthetic Theatre Of War
UHF	Ultra High Frequency
UK	United Kingdom
US	United States of America
VSA	Virtual Ship Architecture
VSAWG	Virtual Ship Architecture Working Group
VS-FOM	Virtual Ship Federation Object Model
WIP	Warfighting Improvement Program

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19. ABSTRACT
This report describes a concept for the Virtual Ship and highlights its potential application throughout all phases of the platform lifecycle. The technical requirements for implementing the Virtual Ship concept are described.